Machinery management provides increased reliability in ethylene plant

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In the early 1980s, the ethylene plant at the E.I. du Pont de Nemours & Company's Sabine River Works petrochemical complex suffered from reliability problems on its large turbomachinery. After two very long outages, they reevaluated their whole system of machine maintenance. In the process, they developed and implemented a stringent Predictive Maintenance program that has been extraordinarily successful. Bently Nevada online machinery management equipment has been an important part of their program.

The ethylene plant

The Sabine River Works, located in Orange, Texas, is a major petrochemical complex. In the mid-1970's, the plant was modified, with more refrigeration added for manufacturing purified hydrogen. The ethylene plant has five major compressor trains (Figure 1 and Table 1).

Train 1: 35,000 hp charge gas compressor train. This train provides the low pressure necessary at the cracking furnaces for high ethylene selectivity and the discharge pressure necessary to process the cracked gas through its cryogenic distillation system.

Train 2: 35,000 hp propylene refrigeration compressor train. This train provides the primary refrigeration for cryogenic distillation.

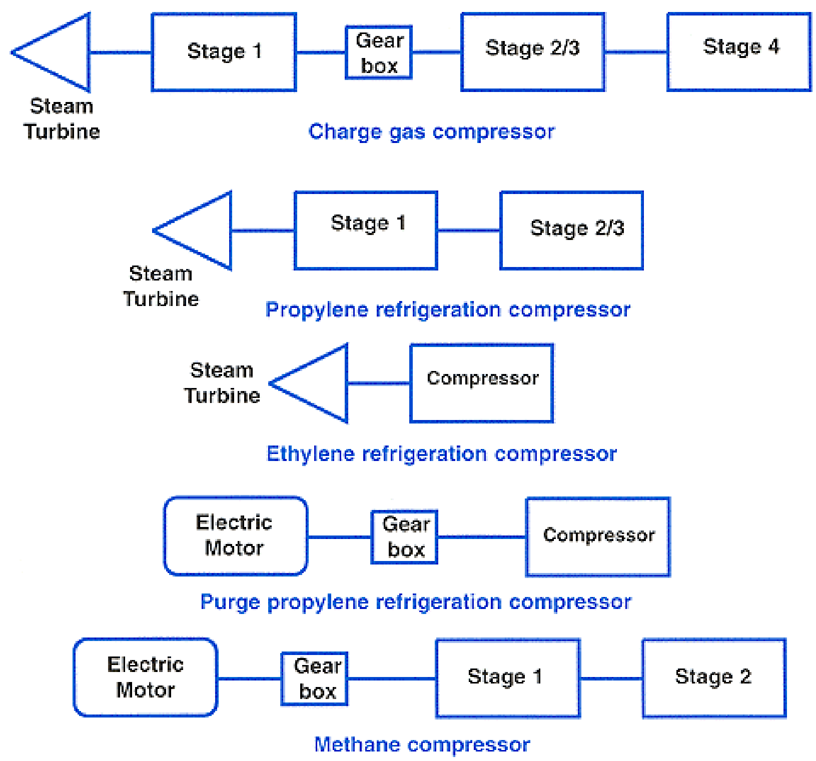


Figure 1
Block diagram showing five major compressor trains.

Train 3: 6,000 hp ethylene refrigeration compressor train. This train provides a lower level of refrigeration for cryogenic distillation.

Train 4: 3,500 hp purge propylene refrigeration compressor train. This train supplies additional primary level refrigeration and refrigeration for the purge recovery facilities.

Train 5: 2,500 hp methane compressor train. This train provides refrigeration for the hydrogen purification facility.

All of the compressor trains are single-line equipment; there are no installed spares. A shutdown of trains 1, 2 or 3 causes the entire ethylene plant to shut down. A shutdown of trains 4 or 5 will not necessarily cause an entire unit shutdown, but will significantly lower plant production. An ethylene plant shutdown, depending on the length of shutdown and the price of ethylene, can cost millions of dollars in lost revenue.

Predictive Maintenance Program

Between 1967 and 1981, the ethylene plant experienced eighteen shutdowns caused by problems with large compressors and turbines. After two long outages in 1980 and 1981, the root causes of the turbomachinery failures were investigated. Du Pont engineers and outside consultants performed rotordynamic analyses on all 12 compressor and turbine rotors. All of the shutdowns were attributable to machinery design problems, machinery degradation or failure to implement improved technology and maintenance techniques. The program focused on three areas for long-term improvement: technological improvements, maintenance training and procedures and shutdown preparation.

Technological improvements

New technologies make machines run better and provide better information. Working with the Original Equipment Manufacturer (OEM) enabled Du Pont to solve design problems that caused turbine blading failures in the charge gas and propylene refrigeration compressor steam turbines. The OEM redesigned the ninth stage blades, so the turbines' resonant frequencies were outside of the turbines' operating speed ranges. Rotor stability analysis of each of the rotor systems was performed and the information was used to upgrade the reliability of the machines. The rotor instability problems on the charge gas compressors, propylene refrigeration compressors, ethylene refrigeration compressor and steam turbine drivers were solved by installing tiltpad bearings on those machines. The compressor trains were retrofitted with dry couplings, to eliminate problems such as "lockup" associated with gear-type couplings. The method for aligning machines was changed from reverse indicator to optical.

Maintenance training and procedures

In the early 1980s, many of the plant's mechanical technicians lacked experience. Therefore, more emphasis was placed on training. The entire 1983 plant outage was filmed and edited into individual videotapes that show how to assemble and disassemble each compressor and turbine. Full-scale models of bearings, couplings and seals were built to assist in training. Technicians and supervisors were shared between sites during overhauls, to improve the technicians' skills and to create a larger pool of skilled technicians. Du Pont also evaluated turbomachinery contractors; they are now being used extensively.

Over the years, plant personnel have attended various Bently Nevada Training Courses, such as Data Acquisition, Machinery Diagnostics, Advanced Machinery Dynamics and 3300 Installation and Maintenance. The information gained has enabled employees to increase their knowledge of machinery behavior.

Shutdown preparation

During a scheduled overhaul, it is important to have necessary spares available and in top condition. After rotors are overhauled, they are stored at the OEM's dedicated, humidity-controlled storage facility. An on-site technician's sole job is to maintain other critical compressor and turbine spare parts. He has inspection tools for performing quality assurance of all incoming parts. All of the special tools and parts required for shutdowns are stored in special, waterproof boxes. Company and industry specialists are consulted prior to shutdowns, and they evaluate each overhaul immediately after it is completed.

Vibration monitoring

When the ethylene unit was built in 1967, Donald Bently was pioneering the use of proximity probes to provide reliable machinery information. He assisted in the installation of single-plane vibration probes and single thrust probes on the turbine portion of the charge gas train. At that time, Bently Nevada did not manufacture monitoring systems, and Du Pont used the information from the probes for information gathering only. In the mid-1970's, the installation was retrofitted with Bently Nevada 3000 Series transducers and embedded thermocouples were added for radial and thrust bearing temperature indication.

In 1982, 7200 System Monitors and 7200 Series XY radial vibration and dual axial thrust position probes were installed, along with Keyphasor® transducers for diagnostic capability. Du Pont also added dual thermocouples, placed in the loaded areas of all the unit's radial and thrust bearings to increase the reliability and accuracy of the temperature indication. This equipment provided dependable data. It also helped convince operating technicians they could rely on the accuracy of readings and provided early detection of equipment problems.

In 1988, a Bently Nevada Dynamic Data Manager® System was added to provide online machinery information for the ethylene unit machinery. The DDM System collects, stores and displays steady state dynamic vibration data, as well as supervisory and operating information. The DDM System converts analog monitor and transducer signals to a digital output for use on a computer system. In 1992, Du Pont added a Bently Nevada Transient Data Manager®2 System and 3300 System Monitors and transducers.

The TDM2 System extends the DDM System's power with transient data

	Train	Driver	Hp	Speed	# Stages
1.	Charge Gas	Condensing Steam Turbine	35,000	4,000/7,100	4
2.	Propylene Refrigeration	Condensing Steam Turbine	35,000	4,200	3
3.	Ethylene Refrigeration	Topping Steam Turbine	6,000	13,000	3
4.	Purge Propylene Refrigeration	Electric Motor	3,500	7,600	4
5.	Methane	Electric Motor	2,500	9,100	2

Table 1
Ethylene plant compressor trains.

acquisition and processing. The transient data it collects during machine startups and shutdowns identifies fundamental machine characteristics, such as balance resonances, amplification factors and mode shapes, that are difficult to identify with steady state data alone.

In 1994, an Engineer Assist™ expert system was added to provide online machinery audit capability on all critical machinery trains in the ethylene unit. Engineer Assist is Bently Nevada's expert system for turbomachinery. It analyzes TDM2 data according to very detailed and sophisticated rules, and explains its conclusions in easy-to-understand diagnostic reports. The TDM2 remote software allows Du Pont to analyze machinery from off-site, via computer and modem.

Du Pont is currently interested in upgrading their system to include Bently Nevada's new Data Manager® 2000 for Windows NT™ and Engineer Assist™ 3.0 systems for enhanced online machinery information capability. They would like to enhance the value of these systems to allow Data Manager 2000 direct access to the process data via a DCS, so process data can be correlated with vibration information.

Predictive Maintenance program results

Before the Predictive Maintenance program was in place, each machine was opened up every two years. Now, the TDM2 System and the process and performance monitoring indicate when maintenance is required. Machines often run three years without maintenance. They may run as long as nine years before a major overhaul, at which time, nondestructive fatigue testing is done.

Two machine saves illustrate how Predictive Maintenance was used to lower maintenance costs and to keep production up.

Machine saves

Charge Gas Compressor instability

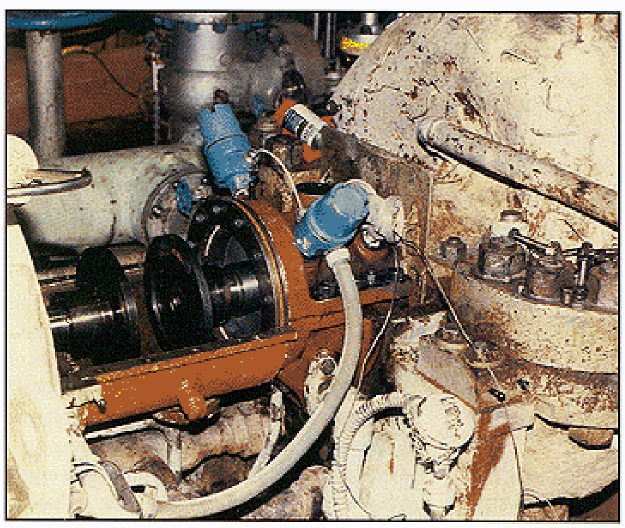
TDM2 and Engineer Assist Systems helped identify a fluid-induced instability on the 4-stage charge gas compressor, and helped maintain production levels until a scheduled shutdown.

In August 1995, subsynchronous vibration levels increased on Stages 3 and 4 of the charge gas compressor, which is monitored by a Bently Nevada TDM System and an Engineer Assist expert system. However, vibration levels were more predominant on Stage 4.

Subsynchronous vibration levels reached 76 μm (3 mils) pp, and would then disappear. The frequency of the subsynchronous vibration on Stage 4 also varied, from 0.38 to 0.5 times running speed. Subsynchronous vibration also became evident on the compressor's second and third stages, which share a common case and rotor. By the end of August, the subsynchronous vibration was continuous at levels 76 to 127 μm (3-5 mils) pp, causing serious concern.

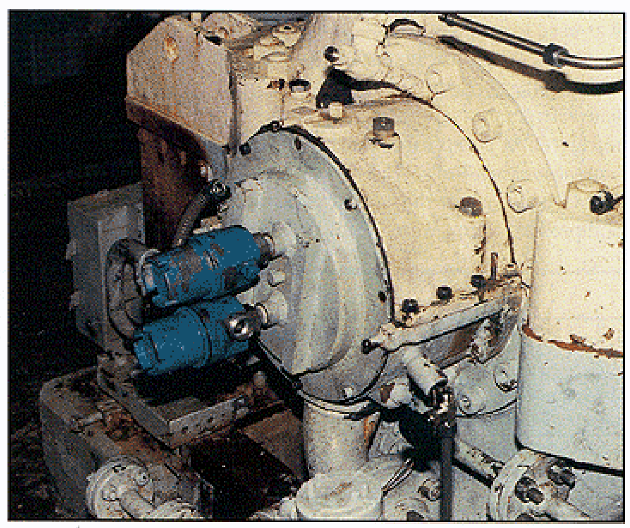
Engineer Assist reported that the machine had fluid-induced instabilities. TDM2 data was sent to Bently Nevada's Machinery Diagnostic Services (MDS) office in Houston for analysis. MDS reached the same conclusion as an independent analysis from another firm: the fluid-induced instability was of aerodynamic origin. However, the plant could not be shut down, because ethylene was selling at record high prices and wasn't available on the spot market.

The compressor's alignment was adjusted online, to change the load on the bearings, and stabilize the machine. Du Pont used steam and water to heat and cool the compressor's support structure, which then changed the alignment and the load on the bearing. Water was



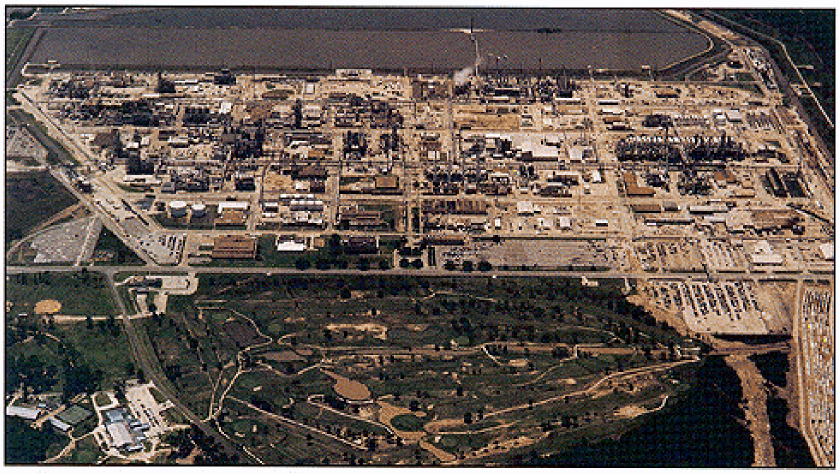
XY proximity probes mounted on an ethylene turbine and compressor.

Photo courtesy of E.I. du Pont de Nemours & Company



Dual voting thrust probes mounted on an ethylene compressor.

Photo courtesy of E.I. du Pont de Nemours & Company



Aerial view of Du Pont's Sabine River Works, Orange, Texas.

Photo courtesy of E.I. du Pont de Nemours & Company

sprayed on the outside of the volute, in an attempt to change the balance seal clearance. Using these techniques, subsynchronous vibration was controlled. Vibration levels were kept under control and TDM2 data was continually monitored.

The instability sometimes reappeared due to changes in load, and at times progressed to a light rub. To protect the machine from a hard rub and subsequent damage while production continued, an interlock driven by a Bently Nevada 3300/65 Dual Vector Monitor was installed. At one times (1X) running speed, the compressor's overall vibration averaged 6 μm (0.25 mil) pp. The interlock was set to shut down the system when vibration reached 25 μm (1 mil) pp at 1X running speed.

The compressor was operated until its scheduled May shutdown, which gave plant personnel time to analyze the problem and determine the correct modification necessary to eliminate the problem. It was determined that the compressor had an aerodynamic cross coupling problem. Several potential fixes, such as a shunt in the balance seals, honeycombed seals, and TAM seals, were analyzed. After all factors were considered, such as stability improvement, fouling susceptibility, and clearance tolerances, balance seals modified with a radial shunt were selected as having the best potential for solving the problem. In addition, the analysis indicated that a change to a load-on-pad bearing arrangement would improve the stability characteristics of the rotor systems.

The OEM later built two new balance seals with radial shunts and modified the bearings to load-on-pad bearings. The compressor hasn't had any indication of an instability problem since.

Instabilities are a significant risk in plants such as Du Pont. The TDM2 System helped identify this instability problem, as well as others. For instance, another compressor had fluid instabilities upon startup when the compressor ingested some aluminum suction drum screens from the demisters.

Charge gas compressor gearbox

The TDM2 System also helped identify broken teeth on a charge gas compressor gearbox. Over a period of several months, the TDM2 System recorded step increases in radial vibration. Each time a part of a gear tooth broke, the unbalance force on the pinion increased, causing increased vibration.

The first gear tooth failure was August 9, 1990, followed by a second failure on October 27, 1990 and a third on November 27, 1990. Each time, when vibration reached an unacceptable level, as analyzed by the TDM2 System, the compressor was shut down. Inspection revealed broken teeth in the gearbox on the pinion helix and heavy pitting was evident on both the pinion and bull gears.

The only spare gears available were a damaged bull gear from a previous failure and a new, hobbed (unfinished) pinion. Rather than grind the gears, which would have taken ten days, the gears were installed in "as hobbed" condition. The gearbox had been scheduled for replacement in mid-1992, but instead was expedited and replaced in January 1991.

Later analysis showed that the problem began when gear teeth were scored after the protective oil film was lost in certain areas. Scoring led to pitting, then to fatigue failure. The newly-designed gearbox with improved features and service factor increase from 1.2 to 1.8 has provided excellent performance.

Conclusion

Predictive Maintenance has been very profitable for Du Pont's Sabine River Works plant. Bently Nevada has helped, by responding quickly with equipment and expertise. Bently Nevada helped Du Pont keep its charge gas compressor running, so they could take advantage of favorable market conditions. Bently Nevada's engineers quickly shipped a 3300 System Vector Monitor and worked closely to design an interlock system to protect the machine.

Technical Associate John Dugas uses the TDM2 System's remote access to work more efficiently. With remote access, TDM2 data is available at his home computer anytime, through the telephone lines. When an operator calls at home, he reviews TDM2 data without traveling to the plant. He has enough experience to correlate most changes in vibration with changes in processes, and with TDM2 data, he can immediately discern the nature of the problem.

A shutdown at Du Pont's ethylene plant also affects the businesses that rely on their products. Another benefit of Du Pont's Predictive Maintenance program is the reputation they have gained for reliability. Since instituting their program in 1982, they have had only three turbomachinery-related shutdowns.